The Honorable Lee Hamilton
The Honorable Brent Scowcroft
Blue Ribbon Commission on America's Nuclear Future
1000 Independence Ave, S.W. Washington, D.C. 20585

Subject: Comments on Reactor and Fuel Cycle Technology Subcommittee Report to the Full Commission, Draft Report, June 2011

Dear Sirs:

Flibe Energy Inc. appreciates the efforts of the Blue Ribbon Commission (BRC) in preparing the Reactor and Fuel Cycle Technology Subcommittee Report and appreciates the opportunities to participate in public meetings and to comment on the draft report.

Flibe Energy Inc. is dedicated to the design, manufacture and operation of liquid fluoride thorium reactors (LFTRs). Members of Flibe Energy, Inc. have previously provided commissioners testimony and provided BRC staff with extensive background material and references on liquid fluoride thorium reactors.

Industry, government and academia are becoming increasingly aware of the potential benefits of use of thorium in liquid-fueled reactors and we are working diligently to disseminate a more full understanding of the potential benefits of LFTR technology. These benefits were successfully demonstrated by the Molten Salt Breeder Reactor Experiment (MSRE) at Oak Ridge National Laboratory (ORNL) between 1964-1969.

The draft *Reactor and Fuel Cycle Report by the Blue Ribbon Commission (BRC) on America's Nuclear Future* could benefit from more developed treatment of liquid-fueled thorium reactors. In particular, future energy policy makers and researchers would benefit from more inclusive word selection throughout this report regarding thorium and molten salt reactors such as LFTR.

Accordingly, Flibe Energy, Inc. offers the attached comments on the current draft report. We would be happy to discuss any of the attached comments with members of the Commission or staff and we look forward to issuance of the full commission's report.

Submitted by:
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Enclosures: Report Excerpts and Comments

<u>Comments on Reactor and Fuel Cycle Technology Subcommittee Report (Draft)</u>

Page iv
Paragraph 3:
Comment: As paragraph 3 points out, the tragic events of Fukushima Daiichi necessitate development of new technologies offering improved safety. At paragraph 3, line 4, we suggest adding the word "new" between the existing words "of" and "nuclear."

Page v
(2) ***No*** *currently available or* ***reasonably foreseeable reactor and fuel cycle technologies****—including current or potential reprocess and recycle technologies—****have the potential to fundamentally alter the waste management challenge*** *this nation confronts over at least the next several decades, if not longer. Put another way, we do not believe that new technology developments in the* ***next three to four decades*** *will change the underlying need for an integrated strategy that combines safe, interim storage of spent nuclear fuel with expeditious progress toward siting and licensing a permanent disposal facility or facilities. This is particularly true of defense high-level wastes and some forms of government-owned spent fuel that can and should be prioritized for direct disposal at an appropriate repository.*

Comment: We agree with paragraph (1) but disagree with paragraph (2) as to prospects for addressing waste management challenges and the time required to make any impact on these challenges. ("*No…reasonably foreseeable reactor and fuel cycle technologies… have the potential to fundamentally alter the waste management challenge… in the next three to four decades.*")

LFTR has the potential to change the spent nuclear fuel (SNF) outlook within 20 years through greatly reduced SNF production and even through consumption of existing SNF. We believe LFTR technology and related chemistry processes could be used to extract and consume available fissile materials in SNF stockpiles, removing much of the long-term SNF storage concerns. We believe a demonstration LFTR can be designed and constructed within 5-6 years, absent inordinate regulatory delays, as was demonstrated at ORNL in the 1960's. A fleet of LFTRs could then put many gigawatts of power on the grid being initially fueled with the available fissile materials extracted from SNF stockpiles and with thorium as the sole input thereafter.

Whereas long-term delays have typically been experienced in the development and licensing of light water reactors, much of the licensing proof sets required by LWRs are not required for LFTRs, namely, LFTRs operate at low temperature alleviating regulatory concerns over high-pressure releases and corresponding high-pressure containment vessels. LFTRs are also inherently stable and offer passive decay heat removal, obviating the need for redundant cooling systems. Thus, we submit that the development and licensing timelines expressed in paragraph 3 could be shortened with regard to LFTR.

Page v (continued)
Last paragraph:

Comment: We agree that safety and nuclear waste are overriding considerations in the post-Fukushima world. We also agree that "*there is a benefit to preserving and developing new options*." We submit that a nuclear reactor technology that offers substantially improved safety and substantially reduced production of nuclear waste, as does LFTR technology, merits more substantial consideration and discussion in the final report.

Page vi
Last paragraph, line 5:
Comment: We suggest that undue emphasis is given to the "scarcity" of public resources and that "*the full range of resources that exist in industry, the national laboratories, and the academic community*," could be reworded to be more inclusive to allow development of new private ventures and new technologies.

Page vi:
2) Longer-term efforts to advance potential "game-changing" nuclear technologies and systems that could achieve very large benefits across multiple evaluation criteria compared to current technologies and systems. Examples might include ***fast-spectrum reactors demonstrating passive safety characteristics that are capable of continuous actinide recycling and that use uranium more efficiently, or reactors that—by using molten salt or gas coolants—achieve very high temperatures and can thereby supply process heat for hydrogen production or other purposes, or small modular reactors with novel designs for improved safety characteristics and the potential to change the capital cost*** *and financing structure for new reactors.*

Comment: We submit that LFTRs similarly offer game changing benefits including passive safety, continuous actinide recycling, increased fuel efficiency, molten salt cooling, very high temperatures useful for hydrogen production, and can be made as small modular reactors with improved capital costs, etc.

We suggest adding "Examples might include fast-spectrum reactors **or liquid fluoride thorium reactors** demonstrating…." The introduction sets the stage for multiple examples, and each of the following performance characteristics are shared by both types. Budgetary commitments to the sodium fast breeder reactors have vastly eclipsed the molten salt projects over the last 50 years, and a more balanced treatment in this report is important to ensure good faith consideration more proportionate funding of molten salt reactors as they offer many of the same benefits as other breeder reactors.

Also, the wording of the example above could be misunderstood by some to imply that fast spectrum reactors are uniquely capable of both passive safety characteristics and continuous actinide recycling. Thermal-spectrum reactors, for example, liquid-fluoride thorium fueled, molten salt cooled reactors, are also capable of both passive safety and continuous actinide recycling. Similarly, the attribution to small modular reactors of "*novel designs for improved safety characteristics*" could be misunderstood to imply that there was an existing safety deficiency and as somehow less beneficial than the "*passive safety characteristics*" attributed to fast spectrum reactors. Small modular reactors can play an important future role, warranting diligence not to inadvertently marginalize their potential.

Page vi-vii
In making this recommendation and the one that follows, the Subcommittee is mindful that federal RD&D funding of all kinds will be under ***enormous budget pressure*** *in the years ahead. It will therefore be* ***especially important to focus scarce public resources*** *on addressing key gaps or needs in the U.S. nuclear RD&D infrastructure and to leverage effectively the full range of resources that* ***exist in industry, the national laboratories, and the academic community****. Furthermore, while the charge of this Subcommittee is to make recommendations to the government, we also want to* ***clearly emphasize the importance and value of continuing and stable industry RD&D investment*** *in reactor and fuel cycle technologies.*

Comment: The tone of this paragraph sets up a mutually exclusive proposition that perpetuates the *status quo*, rather than an expansive, inclusive proposition that encourages new developments. It appears to perpetuate *status quo* and funding streams for national laboratories and current academic institutions perhaps at the expense of other options in the name of an "*effort to target scarce resources*." Consider the tremendous pace of progress demonstrated by the private venture Space X outside of the *status quo* organizations and funding models.

If competition for limited government funding is the concern, wording could be developed to be more inclusive of options for development with a mix of private funding and government funding. We agree with the commission's recommendation to double government funding, particularly since this would allow for a broader range of technologies and development paths. We recommend softening the emphasis on "scarcity" of funding and strengthening the emphasis on the need for increased funding and resources, with more openness to private ventures.

Page vii,
Last paragraph:
Comment: As noted above, we strongly agree with the Subcommittee's recommendation to increase funding to accelerate regulatory processes for new technologies.

Page x
Comment: We agree with paragraph 2 and would like to see similar thoughts carried out in more paragraphs within the body of the study.

On page x:
We ***should be interested in new reactor and fuel cycle technologies <u>to the extent</u> that they offer <u>tangible</u> benefits compared to currently available technologies and <u>to the extent</u> they make it <u>possible to maximize</u> the energy contribution from nuclear power <u>while also minimizing</u> associated costs and risks.*** *In other words, the Subcommittee takes the view that future decisions concerning the development and deployment of advanced reactor and fuel cycle technologies* ***should be driven by broader energy policy objectives****,* ***rather than by any a priori commitment to a particular system or fuel cycle option****.*

Comment: The word choice and tone of this paragraph again inclines toward maintaining the *status quo* and could be reworded with more care and consideration to not marginalize new reactor and fuel cycle technologies. In particular, use of "to the extent", "tangible", "maximize", "minimize" seems to erect hurtles or at least resistance to such new reactors or fuel cycles. Balanced evaluation of relative safety, performance, cost, is sufficient without use of such qualifying, if not potentially marginalizing, word choices.

Page xi
First paragraph
Comment: This paragraph properly reflects the "game changing mood" throughout America after the incident at Fukushima. Perhaps a paradigm shift may be warranted in the way research efforts are identified. Wording to allow for private industry and corporations to identify research objectives might provide for more timely results of applicable research in national laboratories and university settings. Please consider expanding "*there are a number of remaining uncertainties*" to include "*still to be addressed*" as the finality of the statement, otherwise, could be interpreted as conclusive deficiencies rather than challenges that may be overcome with continued research and development.

Page xi
Last paragraph:
*Our national **objectives are not served** by the development of **reactors that are very efficient, but that do not mesh**, for example, with a **reprocessing or disposal** system. Thus, all the components in an advanced fuel cycle should be examined as part of a system in which all the components should work together.*

Comment: We note that LFTR technology is both very efficient and meshes quite well with reprocessing or disposal systems. In particular, LFTRs are extremely efficient in consumption of fuel and produce vastly reduced amounts of long-lived nuclear waste. The shorter-lived LFTR wastes can largely be separated and used in commercial industry with the small remaining amount being readily stored for hundreds instead of thousands of years.

Page xii
Comment: We note again the emphasis on "*scarce resources*" that could unduly limit consideration of new technologies and merely preserve the *status quo*. The tone of this paragraph could have the unintended result of potentially yielding truly advanced nuclear technology progress to China, India, France, *etc*.

Page 1:
Specifically, we looked at the following criteria:
- *Safety of reactors and fuel cycle facilities*
- *Waste management*
- *Cost*
- *Sustainability*
- *Promoting nuclear non-proliferation goals*

• *Promoting counter-terrorism (physical security) goals*

Comment: We note that LFTRs score very high in each of these categories and include a summary of LFTR performance in these and other categories at the end of these comments.

Page 11-12:

Systems that result in nearly ***complete consumption of natural uranium*** *in a once-through cycle, while theoretically possible, are not considered realistic.*

Other variations on the current ***once-through cycle*** *could involve the use of* ***thorium fuels****, which* ***might****—in some once-through configurations—produce* ***modest reductions in waste streams and plutonium production****.* ***Otherwise, however, waste disposal and non-proliferation metrics for once-through thorium fuels are essentially the same as for uranium fuels****. Higher uranium enrichments needed to drive these cycles might offset savings in enrichment capacity and natural uranium consumption.*

Comment: These statements are not applicable to the liquid thorium fuel cycle. In particular, uranium 233 bred from thorium can be fully consumed in fuel form through continuous cycling of the fuel through the core with more than modest reductions in waste streams and plutonium production. Indeed, LFTRs are configured to produce no weaponizable plutonium and can be configured to produce the non-weaponizable Pu-238 desperately needed by NASA for deep space exploration.

We suggest that Page 11 of Section 2.2 on fuel cycles, and the report as a whole, should more carefully distinguish between use of thorium in solid-fueled reactors and in liquid-fueled reactors in broad statements about thorium. The report could also specifically address the potential improvement towards closing the fuel cycle offered by use of liquid fuels and uranium bred from thorium.

Page 13:

Although graphite moderated reactors can and did operate on natural uranium, future HTRs are being designed to operate on enriched uranium (often higher than LWR enrichment levels), ***while salts may also be used for fluid fuels that would enable thorium-based fuel cycles****.*

Comment: Introduction of molten salts as an afterthought with a "while", "may also" and "would" discounts the successful and well-documented demonstration by the MSRE at ORNL of use of salts for fluid fuels that <u>did</u> enable thorium-based fuel cycles. LFTR technology has tremendous potential and the basic physics, operating fundamentals and basic architecture were successfully demonstrated over five years at ORNL. Treatment of this technology should more properly reflect the actual level of development and potential benefits. Please consider a separate paragraph here dedicated to more detailed treatment of salt-based liquid fuels.

Page 17:

However, there are also examples where fuel fabrication may not be needed at all, such as in certain molten salt reactor designs with periodic or continuous fuel reprocessing.

A breeder fuel cycle with thermal reactors operating with uranium/thorium fuel was demonstrated at Shippingport in a specially designed light water reactor in the 1970's.

Breeder cycles ***are also possible using molten salt reactors with thorium-bearing fluid fuel****.*

However *the more conventional solid fuel has made* ***sodium-cooled fast reactors the primary choice to date among nations*** *that have pursued the breeder fuel cycle. Once started, the "breeder" fuel cycle would displace the need for enriched uranium fuel even for starting new reactors; it would also continue to satisfy the waste management goal of greatly reducing transuranics in the waste streams. On the other hand, in the fast-spectrum uranium fuel cycle the quantity and mass flows of transuranics actively circulating through different fuel cycle facilities during recycle is greater compared to a once-through fuel cycle.* ***Breeding cycles involving thorium generally have much smaller transuranic inventories, <u>but are less effective</u> in transmuting transuranics in existing uranium fuel inventories****.*

From a waste management standpoint, if operated for a century or more a continuous recycle can at least theoretically achieve a balance in which all spent fuel is reprocessed, with no spent fuel requiring disposal as the system continues to operate.

Comment: Again, the positioning of molten salts as an afterthought to fast breeders, and again framed with "however" and "but" marginalizes the very potential that those passage purport to set forth. Please treat the benefits separately from any negative considerations, as the immediate juxtapositioning of the two risks appearing overly dismissive of those benefits.

Page 23:
But currently no nation has ever achieved a fully closed nuclear fuel cycle, including spent fuel reprocessing, breeder reactors, and the associated fuel fabrication, waste stream management systems, etc. The closest any country has come to this is France, which operates a large reprocessing plant at La Hague.

Comment: LFTR could potentially be the first fully-closed fuel cycle, which is most readily obtained by using a liquid fuel form.

Page 26:
Relative to the once through fuel-cycle, different nuclear energy system strategies involve a wide range of trade-offs in terms of safety, cost, resource utilization and sustainability, waste management, and the promotion of nuclear nonproliferation and counter-terrorism goals.

Comment: LFTR merits a high-score in each of these categories without major tradeoffs between these categories. Please refer to the LFTR scoring discussions at the end of the comments.

Page 30:
Measuring non-proliferation or counter-terrorism characteristics of various nuclear energy systems is far from straightforward; among the considerations that come into play is what quantities and forms of sensitive nuclear material (including **separated plutonium***) exist at various points in the fuel cycle; what level of* **uranium enrichment** *capacity is needed to support the fuel cycle; and whether the materials separated as part of a given fuel cycle would be particularly attractive and/or particularly susceptible to undetected diversion for malicious purposes.*

Comment: LFTR does not require plutonium separation or uranium enrichment and has inherent strong deterrents to diversion of materials, namely production of U-232 and closely matched fuel conversion and consumption rates.

Page 31:
When comparing the potential benefits and liabilities of different nuclear energy systems (fuel cycles and deployment strategies), for example, numerous assumptions must be made—many of them involving information that is not available for advanced technologies that are still under development, including:
1. The growth rate of nuclear electricity production
2. Current and ultimate performance, cost, and reliability of competing nuclear energy system technologies
3. Waste generation rates, composition, and characteristics
4. Measures for non-proliferation, nuclear material and energy security, and safeguards in an uncertain future domestic and international environment
5. Price and availability of natural resources into the future
6. Constraints on the size/capacity of future waste disposal sites
7. The importance of various radionuclides (e.g., TRU vs. fission products) to the performance of unknown future repository sites

Comment: Again, please refer to the LFTR scoring discussion at the end of the comments.

Page 32-34:
The defining feature of the fourth system is a ***high-temperature reactor*** *that can achieve temperatures greater than* ***600°C*** *(light water reactor outlet temperatures are about 300°C) operating on a once-through fuel cycle. This system was selected because it has the potential to displace the use of fossil fuel across all energy sectors, not just electricity production. Examples of energy-intensive industries where high-temperature nuclear process heat could be used are cement and steel manufacturing, and petroleum refining (see Figure 11). High-temperature nuclear process heat could also be used to produce hydrogen for transportation fuels by directly decomposing water instead of using electrolysis or decomposing natural gas, and the high power conversion efficiency can also make dry cooling and thermal desalination of seawater practical.*

Many additional system options exist that have received varying levels of study. For example, nuclear energy systems that involve a ***fast-spectrum reactor capable of achieving very high temperatures by using a molten salt or gas coolant****, or a* ***thermal-spectrum, high-temperature molten-salt reactor using thorium have also been proposed****. Such systems could potentially offer many of the combined benefits of the alternatives listed.* ***However****, these systems have* ***not received systematic study*** *and the component technologies for these types of systems are* ***less well developed****.*

Comment: The MSRE was a systematic study with a remarkable level of development given a very limited budget and short time frame. We would caution against wording that would dissuade further development of molten-salt reactors because of discounting these earlier ORNL development efforts and current development efforts underway.

Page 38:
Uncertainty over capital costs will continue to persist until construction of the first few new advanced LWRs occurs in this country.

Comment: Consider broadening beyond just LWRs.

Page 39:
"(uranium but also possibly thorium)"

Comment: Use of "and" would be more inclusive and less marginalizing of thorium.

Page 42:
The reactor technologies associated with the four fuel cycle options can be safeguarded effectively to provide timely detection of any attempt to divert fresh or irradiated fuel, because the fuel elements and assemblies can be accounted for as items.

Comment: LFTR can be safeguarded against diversion through monitoring of reactor operation, since the conversion and consumption rates can be nearly equally matched such that any attempted diversion would result in the reactor coming off-line. Because the fuel is fully consumed, the need for safeguarding waste products is greatly reduced.

Page 42:
For these reasons, power reactors are generally viewed to create substantially lower proliferation risk than enrichment and reprocessing.
All four of the fuel cycle options described above require substantial and large-scale deployment of enrichment infrastructure. While the ***high temperature reactor*** *and modified open fuel cycle options* ***require more and less enrichment capacity*** *than the baseline open cycle, respectively, the* ***differences are modest and do not change qualitatively the proliferation risks posed by enrichment****.* ***Even for the fully closed cycle, substantial enrichment capacity remains necessary*** *during the transition to a nuclear fleet based on fast reactors. The proliferation risks associated with enrichment depend very strongly on how it is deployed.*

Comment: LFTR is a high temperature reactor that does not require enrichment capacity. LFTR can be started on any fissile material, but preferably on U-233, which could be extracted from the U-233 stockpile at ORNL. In another scenario, plutonium stockpiles could be used in a variation of a LFTR to effectively consume the plutonium while converting thorium into U-233 as a seed fuel for more LFTRs.

Page 43:
Counter-Terrorism – Terrorism remains a global problem. Terrorism risk from civil nuclear energy systems arises from two primary sources: the potential for sabotage of nuclear facilities or transport to cause radiologic releases, and the potential for theft of nuclear materials for use in improvised nuclear explosives. Counterterrorism efforts to reduce these risks involve a combination of international cooperative activities and national activities. The protection of nuclear facilities and materials is a national responsibility, but there exist a

variety of international efforts that the U.S. leads or participates in to assist countries in strengthening this protection; these efforts merit further and increased support.
Because nuclear reactors operate with ***substantial amounts of stored energy*** *and inventories of short-lived fission products, their safety systems require effective physical protection from acts of radiological sabotage.*

Comment: LFTRs do not have substantial amounts of stored energy as they operate at low pressure and with a chemically stable coolant/fuel form. There is no risk of high-pressure atmospheric radiological releases. Also, the salts will not react with flood waters, ground water or the atmosphere.

Page 44:
All spent fuel reprocessing *methods that chemically separate fission products* ***produce a plutonium-bearing product stream*** *with* ***radiation levels that are too low to provide self-protection****, particularly in light of the willingness demonstrated by many terrorists to self-sacrifice. The risk of theft of reprocessed plutonium must be taken very seriously, because even a low-yield event from a crude terrorist nuclear explosive design would have devastating consequences in a crowded urban area, as would the disruption caused by the fear of additional explosions in other cities.*

Comment: LFTR does not produce weaponizable plutonium, thus its spent fuel reprocessing would not fit into the overly inclusive "all spent fuel reprocessing" statement above. Also, the U-232 present in the LFTR fuel after a period of operation decays to a hard gamma emitter which is a powerful self-protection. These gamma emissions would damage weapons electronics, technicians, and give off a readily detectable signature.

Page 47:
Analyses indicate that about 85% of the public and occupational risk from the nuclear fuel results from uranium mining and milling (none of the analyses account for depleted uranium disposal).

Comment: Preparation of thorium fuels would not present the same level of risk as uranium preparation, in particular because thorium is already a byproduct of existing rare earth mining and the liquid thorium fuel does not require the types of milling and fabrication required by solid uranium fuels.

Page 47-48:
As a consequence, the amount of uranium mining and milling required, and the resulting long-term risk from the nuclear fuel cycle varies significantly. In particular, the long-term risk from the entire fuel cycle is reduced by 17% for *Reactor and Fuel Cycle Technology Subcommittee 48 June 2011 Blue Ribbon Commission on America's Nuclear Future* *the LWR MOC and 85% for the closed-cycle fast reactor nuclear energy systems while long-term risks for the HTR nuclear energy system are similar to those of LWRs. Alternatively, the recovery of uranium from seawater, does not produce mill tailings and thus provides a reduction of risk potentially comparable to the closed-cycle fast reactor system.*

Comment: We suggest inclusion of the reduction in risk of preparation of liquid thorium fuels relative to solid-uranium fuels.

Page 48-49:

*Concerning repository wastes, the once-through HTR system generates a substantially greater volume of SNF than the OT LWR because, even though the HTR SNF contains less uranium, transuranics, and fission products, the **fuel is bulkier because the graphite moderator is part of the fuel**. The LWR MOC generates about the same waste volume as the OT LWR and the closed-cycle fast reactor system generates about 40% more waste than the OT LWR waste destined for a repository. These outcomes are the result of two competing effects: on one hand the volume of vitrified HLW is significantly less than the volume of SNF but on the other hand reprocessing and recycled fuel fabrication produce GTCC wastes (e.g., fuel assembly structural metal and cladding, TRU-contaminated equipment and trash) that yield a net increase in the total volume.*

Concerning low-level wastes destined for near-surface disposal, the LWR MOC and closed-cycle fast reactor nuclear energy systems result in volume decreases of 20% and over 95%, respectively, relative to the LWR once-through systems. The decreases are driven by the reduced need for uranium, (primarily production of uranium mill tailings but also depleted uranium and LLW from processes in the front end of the fuel cycle) in the alternative systems that dwarfs the additional volume of LLW produced by reprocessing and recycled fuel fabrication facilities. The volume of near-surface waste from the HTR system is similar to LWRs. The LLW (near-surface wastes less mill tailings) produced by the OT LWR, LWR MOC, and HTR are about the same and are dominated by the front end of the fuel cycle. The LLW from the closed-cycle fast reactor is about 40% less than that from the OT LWR cycle because there is much less front-end activity.

Comment: We suggest inclusion of the reduction in long-lived waste of liquid thorium fuels relative to solid-uranium fuels.

Page 50:

The once-through HTR system has about 25% lower repository space requirement because the HTR has a higher thermal efficiency, which means fewer fissions are required to produce the same amount of electricity as the once-through LWRs. The closed cycle fast-reactor system requires about 75% less repository spacing if a major fraction of the TRU are destroyed by sustained recycle instead of being part of the HLW waste stream that is disposed of in the repository. If the TRU are destroyed by sustained recycle, and in addition cesium and strontium are separated during reprocessing so they are not sent to the repository, then the repository space requirement decreases by 95 to 98%. However, achieving this requires an alternative way of managing the recovered cesium and strontium such as decay in a storage facility for a few centuries, which raises an entirely new set of siting, cost, security, and institutional control issues.

Comment: LFTR fully consumes the U-233 that is bred from thorium, leaving very little long-lived waste. The majority of LFTR waste is stable within decades while the remaining is stable within hundreds of years, compared to the thousands of years required for existing SNF stockpiles.

Page 50:

Analysis and Recommendations. Compared to the once-through LWR system, the modified-open cycle LWR system offers modest advantages in terms of uranium resource utilization, yielding a tailored waste form for most repository wastes, a modest reduction in enrichment requirements, and reduction of the volume of wastes requiring near-surface disposal such as mill tailings and depleted uranium tails. These advantages come with disadvantages: increased fuel cycle costs, increased physical security costs and risks for the protection of separated plutonium and fresh MOX fuels, and increased proliferation risks depending upon how reprocessing infrastructure is deployed compared to enrichment infrastructure. On balance, the subcommittee sees no compelling reason to encourage industrial-scale deployment of this nuclear energy system in the U.S. at this time.

Compared with either of the LWR systems, the once-through ***HTR system has the potential to yield some compelling advantages****: the* ***potential for a major reduction in the use of fossil fuels****, which should lead to commensurate global climate and energy security benefits, and a* ***significant reduction in repository space requirements****.* ***Most disadvantages of this system are modest:*** *absence of a waste form tailored to the disposal environment, and the use of uranium having enrichment levels about twice that of once-through LWR fuels.* ***The one major disadvantage of the HTR system is that only one demonstration reactor resembling projected future HTR designs was built and operated, and that proved to be very unreliable and costly.*** *As a consequence, the* ***HTR system will require substantial RD&D to determine whether it can become sufficiently reliable and economic so that deployment can be justified****, all things considered.* ***The Subcommittee recommends that the RD&D program on high-temperature reactors be continued.***

Comment: LFTR offers similar advantages and potentially fewer disadvantages and warrants similar positive treatment in word choice received by HTR above. The MSRE was also a working demonstration reactor, achieved with considerably less capital investment than HTR. This paragraph could be interpreted as an *a priori* commitment to a particular reactor type and fuel cycle, contrary to recommendation of earlier passages.

Page 51:
Examination of the attributes of HTR and closed-cycle, fast-spectrum systems in Table 5 leads to the possibility that hybrid alternatives ***might be*** *attractive. For example,* ***molten salt reactors do not use metal cladding or structures in their reactor cores, and thus can operate at the same temperatures as HTRs. Fluid fuels eliminate the requirements to fabricate fuel assemblies from recycled material, and thus can use relatively simple chemical separations that maintain high radiation levels and self protection. The radioactivity and inaccessibility of these streams should partly ameliorate proliferation and terrorism concerns****, although methods for applying IAEA safeguards* ***remain to be*** *developed. A prototype molten salt nuclear reactor (the Molten Salt Reactor Experiment) operated in the U.S. from 1965 to 1969 and at one point the U.S. had a program to develop a full-scale reactor. Substantial interest in this technology, today commonly called the Liquid Fluoride Thorium Reactor, has reemerged due to its capacity to operate at high temperatures with thorium fuel.* ***However****, as might be evident, the system described here* ***is not as well developed as the HTR and closed-cycle fast reactor nuclear energy systems discussed above****, and a* ***major RD&D program would be required to bring it to fruition****. The Subcommittee recommends that DOE* ***perform a detailed technology assessment*** *to*

determine the status of this technology as a basis for deciding whether it should be pursued further.

Comment: We agree with the favorable treatment of LFTR in the first paragraph and recommend extension of this treatment to the other areas of the report addressed above. In particular, this degree of treatment should be included in Section 2.2.

Despite the disparity in previous R&D funding, we submit that LFTR relatively close to full development in terms of future R&D required relative to the HTR. There is no reason initial R&D could not be committed to both LFTR and HTR before definitely settling on the major R&D recommended earlier for the HTR.

Consider "*will need to be developed*" in place of "*remain to be developed*."

Page 52:
Thorium-based fuels in once-through cycles ▪ Offer additional resources but other benefits and issues are essentially the same as for the once-through alternative.
▪ Reduced amount of transuranic (TRU) elements in the used/spent fuel does not mean that the radiotoxicity of the spent nuclear fuel is lower or that the long-term risk from a repository containing thorium-based fuels is significantly lower than the risk from a repository containing uranium-based fuels.

Comment: The statements above are not applicable to use of thorium in liquid fueled form in a LFTR.

Page 52:
Small modular reactors ▪ A strategy to change the approach to manufacturing, financing, and deploying reactors, rather than a distinct nuclear energy system or technology. The question is whether modular designs can offer advantages in terms of cost and safety.
▪ Reactor alternatives in Table 1 (including the baseline), variants of these alternatives, and light-water reactors could theoretically all be implemented using "small" designs.
▪ Small designs do not fundamentally change the waste management issues associated with the reactor type in question*.*

Comment: Size alone does not fundamentally change the waste management issues, but use of a liquid fuel form as in LFTR does.

Page 52-53:
The fact that there are no clear winners among the advanced fuel cycle concepts currently under consideration ***suggests a policy to keep multiple options open****.* ***That said****, certain fuel cycle strategies and technologies are* ***clearly better developed than others****—research in some areas has been* ***underway for decades*** *and it is possible that* ***more mature technologies could be implemented more quickly****, perhaps within a* ***few decades****. Other concepts are* ***barely at the proof-of-principle stage*** *and would require* ***substantial investments of time and funding*** *(and in some cases a* ***number of revolutionary technical developments****) to bring them to a* ***level of maturity sufficient to evaluate their suitability for further development*** *and*

potential implementation. Consequently, the level and duration of R&D effort needed to advance these Reactor and Fuel Cycle Technology Subcommittee 53 June 2011 Blue Ribbon Commission on America's Nuclear Future concepts varies widely. ***Ironically, funding needs for technologies that are relatively more developed can be greater than for technologies still in an earlier phase of the RD&D process****—particularly in the case of technologies that are ready to be demonstrated.*

Comment: ***"Ironically, funding needs for technologies that are relatively more developed can be greater than for technologies still in an earlier phase of the RD&D process."*** We strongly agree - in terms of R&D dollars required, versus dollars already spent, LFTR is not less mature and would not require a few decades. The original MSRE was operational within four years of the program start for less than $100 million in present day adjusted dollars. Also, LFTR is not "barely at the proof-of-principle stage" and does not need "*revolutionary technical developments."*

Page 53:

Advances in nuclear reactor and fuel cycle technologies ***may*** *hold* ***promise*** *for achieving substantial benefits in terms of broadly held safety, economic, environmental, and energy security goals,* ***but continued RD&D will be required****. Subcommittee members hold different views about the commercial promise of technologies for closing the fuel cycle and about the strength of the rationales often cited in arguments for (or against) moving away from the once-through fuel cycle as currently employed in the United States.*

Comment: Use of "promise" is sufficiently vague without further marginalizing these advances with "may" and "but." Use of "and" instead of "but" would be more inclusive of advances in reactors and fuel cycles.

Page 53:

(2) ***No*** *currently available or* ***reasonably foreseeable reactor and fuel cycle technologies****—including current or potential reprocess and recycle technologies—have the* ***potential to fundamentally alter the waste management challenge*** *this nation confronts over at least the* ***next several decades****, if not longer.*

Comment: We disagree as stated earlier, in particular with regard to LFTR reactors and liquid fuel thorium fuel cycles.

Page 56:

R&D OBJECTIVE 2: Improve the affordability of new reactors: New reactor designs, such as ***small modular reactors (SMRs)*** *and* ***high-temperature reactors (HTRs)*** *may offer* ***improved safety and economics*** *and other desirable characteristics. To pursue these opportunities, DOE intends to develop advanced reactor concepts, technologies and tools for high-performance plants;* ***support R&D on small modular reactor concepts****, including* ***sponsoring cost-shared research related to design certification; and design*** *and develop safety methods for high-temperature reactors using graphite-based fuels.*

Comment: We strongly agree with these recommendations.

Page 56:

For the once-through fuel cycle, DOE plans to develop fuels that would increase the efficient use of uranium resources and reduce the amount of spent fuel generated for each megawatt-hour (MWh) of electricity produced—essentially by increasing the burn up of once-through fuels. This would include evaluating the use of ***non-uranium materials (e.g., thorium)*** *as reactor fuel options.*

Comment: Consider "*This would include evaluating the use of thorium or other non-uranium materials as reactor fuel options."* Thorium offers tremendous potential and every care should be taken in this report for thorium to be fully considered, not merely as an alternative to existing fuels, or worse as an afterthought, but on its own merits.

Page 56:
Prior to beginning major R&D work on these three fuel-cycle options, DOE intends to analyze a number of related issues, including the availability of fuel resources for different fuel cycle and reactor deployment scenarios;

Comment: LFTR relies on inexpensive, abundant thorium as the long-term fuel and can be made in factories for modular deployment with unprecedented siting flexibility, in part due to the potential for dray/air cooling of LFTRs.

Page 57:
Cross-Cutting R&D: DOE's 2010 roadmap also calls for ongoing R&D in a number of enabling, cross-cutting technology areas:

- *structural materials*
- *nuclear fuels*
- *reactor systems*
- *instrumentation and controls*
- *power conversion systems*
- *process heat transport systems*
- *dry heat rejection*
- *separations processes*
- *waste forms*
- *risk assessment methods*
- *computational modeling and simulation*

Comment: We encourage these recommendations for funding, in particular for computational modeling of liquid fueled designs, gas turbine power conversion systems, and dry heat rejection.

Page 58:
For example, current industry willingness to invest substantial financial resources into the development of small, modular reactors based on light water reactor technology provides evidence for the commercial potential of this technology. As R&D advances additional new nuclear energy technologies to the stage where commercial-scale demonstration may be warranted, federal cost sharing of development costs will remain the most appropriate approach to incentivize their commercial-scale demonstration.

Comment: We aim to soon demonstrate industry willingness to invest substantial financial resources into the development of small, modular LFTRs and look forward to similar federal cost sharing of development costs as the most appropriate approach to incentivize commercial-scale demonstration of LFTR.

Page 61:

LWR SMR Licensing Technical Support*: This new program is proposed to be split out of the Reactor Concepts R&D effort and to stand alone starting in FY 2012. The purpose is to* ***support first-of-a-kind engineering and design certification activities for small modular water-cooled reactor designs*** *through cost-shared arrangements with industry partners in order to accelerate deployment.*

Reactor Concepts RD&D*: This program aims to develop new and advanced reactor designs and technologies. Specific areas of R&D (there are no demonstration activities planned in the immediate future) are designed to address technical, cost, safety, and security issues associated with new reactor concepts.* ***Individual projects within this program include small modular (non-light water-cooled) reactors*** *advanced concepts R&D, the Next Generation Nuclear Plant demonstration project (NGNP), and other advanced reactor concepts. In addition, in cooperation with EPRI the program will develop advanced technologies for extending the life of existing light water reactors under the Light Water Reactor Sustainability program.*

The largest share of the FY2011 budget request for reactor concepts (about 40 percent) is for the Next Generation Nuclear Plant Demonstration Project (NGNP), which aims to demonstrate electricity and/or hydrogen production with a high-temperature nuclear energy source.

Comment: Is there any reason that the small modular reactor licensing technical support could not be broadened to all SMRs and not just LWR SMRs? Licensing technical support is needed for liquid-fuel forms, without being relegated to "projects" in the more vague RD&D category.

Page 65:

These facts provide the basis for the Subcommittee's recommendation that ***5 to 10 percent of federal nuclear energy R&D funding*** *be provided directly to the NRC to fund an independent program of anticipatory research and efforts to develop licensing frameworks for* ***advanced reactor and fuel cycle*** *technologies.*

Comment: We submit that the potential merits of advanced reactor and fuel cycle technologies warrant more than 5-10 percent of the R&D funding.

Page 69:

There are limited to no thermal transport and safety analysis flow loops available in the US today for liquid metal or molten salt reactor simulation and testing, or for computer model validation and verification for these systems, or for safety analysis for use in licensing proceedings for these reactor technology types.

Comment: We are working to build a hot salt loop and computer models for LFTR reactors and suggest rewording this passage to highlight the need for and call for more of such resources rather than highlighting merely the scarcity of them.

Page 75:
Finally, the Subcommittee supports the NRC's current performance-based approach to developing regulations for advanced nuclear energy systems.

Comment: We strongly support the Subcommittee's position regarding performance-based regulation.

Page 90:
Having reviewed different reactor and fuel cycle technologies and DOE's current R&D program, the Subcommittee concluded that ***advanced nuclear technologies hold sufficient promise for helping to address broadly held safety, security, and sustainability objectives*** *and that continued federal investment to* ***research, develop, and demonstrate these technologies is warranted****. "****Game-changing****" technology advances that could advance multiple objectives simultaneously, in particular, have the potential to deliver substantial long-term returns on public investment and* ***should be the focus of sustained, strategically targeted, and well-coordinated federal RD&D efforts****.* ***Given*** *that many of these advanced technologies* ***will take years to develop, however, we believe it is also appropriate to focus attention on nearer-term improvements*** *that could enhance the performance and safety of* ***currently available technologies****, specifically the light-water reactor and once-through fuel systems that dominate the current fleet as well as the capacity expansions planned over the next two decades in different parts of the world. In the aftermath of Fukushima, in particular, renewed attention to safety issues is appropriate and to be expected.*

Comment: LFTR is just such a game changing technology and should be the focus of sustained, strategically targeted, and well-coordinated federal **and private** RD&D efforts.

Page 91:
Another important question for the Subcommittee, and one that is directly relevant to the main charge before the BRC as a whole, was ***whether any*** *known or anticipated advances in* ***nuclear technologies could fundamentally alter the waste management challenge*** *the United States confronts over the next few decades. We concluded that the* ***answer to this question was no****. In other words,* ***we see no technological development*** *or change that would* ***weaken the case for moving forward as expeditiously as possible to establish permanent disposal capacity for spent nuclear fuel and high-level waste****. We believe this conclusion follows from any realistic assessment of the nature and quantity of high-level waste and fuel that must be managed and of the time required to successfully develop, commercialize, and deploy new nuclear energy systems. Nor does it depend how one views the desirability or feasibility of ultimately closing the fuel cycle. Different countries have approached the decision about whether to pursue a closed vs. open fuel cycle with different sets of priorities; the Subcommittee, for its part, did not reach consensus on this point. In our view it would be* ***premature for the United States to commit to any particular fuel cycle option*** *as a matter of government policy at this time, especially in light of the* ***large uncertainties that surround many of the component technologies****. Rather, we believe the* ***appropriate emphasis for the***

***U.S. program should be on preserving options that have high potential** to deliver benefits across multiple evaluative criteria (safety, cost, resource utilization, non-proliferation, etc.).*

Comment: We agree strongly with the recommendation to preserve high-potential options, such as LFTR.